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Building Reflective Practices in a Pre-service Math and Science Teacher Education Course That Focuses on Qualitative Video Analysis

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ABSTRACT

The use of video for in-service and pre-service teacher development has been gaining acceptance, and yet video remains a challenging and understudied tool. Many projects have used video to help pre-service and in-service teachers reflect on their own teaching processes, examine teacher–student interactions, and develop their professional vision. But rarely has video been used in ways more akin to qualitative education research that is focused on student learning. Even more rarely has this focus occurred at the earliest stages of pre-service teaching when students have not yet decided to pursue teaching careers. Yet here we argue that there are benefits to our approach. We examine a course for prospective pre-service math and science teachers at the University of California, Berkeley, that engages participants in qualitative video analysis to foster their reflective practice. This course is unique in that the prospective pre-service teachers engage in qualitative video analysis at a level characteristic of professional educational research, in that their analysis focuses on student learning of math and science content. We describe classroom activities that provide opportunities for the pre-service teacher participants to better observe, notice, and interpret their students' sociocognitive activity. The course culmination project involves participants developing and teaching lessons in a high school classroom. The participants then videotape the lessons and conduct qualitative video analysis. Results include detailed examples of two selected prospective pre-service teachers demonstrating coherent and effective approaches to conceptualizing the learning and teaching of mathematical and science content along with some potential design principles for building reflective practices through qualitative video projects.

KEYWORDS

Pre-service teachers;
qualitative analysis;
reflective practices; video

The use of video for in-service and pre-service teacher development has been gaining acceptance. Video can serve many useful purposes, and yet, it remains an understudied tool. Many projects have used video to help in-service teachers develop their professional vision (e.g., Sherin & van Es, 2009). An important part of a teacher's professional skill set is to be able to observe and notice students' social and cognitive behaviors in the classroom as a means of making inferences about their learning. The ability to observe this behavior is what is known as reflective practice (Zeichner & Liston, 1996).

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Existing research shows that learning to notice can be challenging (e.g., Jacobs, Lamb, & Philipp, 2010; van Es & Sherin, 2002). Although there are many approaches to building this skill set, here we focus on a novel means of developing reflective practices: qualitative video analysis conducted at a level characteristic of professional educational research.

Our context focuses on prospective pre-service teachers who have not yet enrolled in a teacher education program but are taking a first class to explore math and science teaching. This class includes a qualitative video analysis project. The project provides opportunities for the prospective pre-service teachers to observe, notice, and interpret high school (HS) students' social and cognitive dimensions of content learning (i.e., their sociocognitive activity). The prospective pre-service teachers in the class plan, teach, videotape, and conduct qualitative video research on an HS lesson that centers on an open-ended math or science content problem. Through this final project and in conjunction with other course activities, the prospective pre-service teachers are able to go beyond their own personal experiences in interpreting HS student learning and thereby build reflective practices. In this article, we describe key course activities, give excerpts of prospective pre-service teachers' work demonstrating reflective practice, describe contributing design principles, and explore some factors that may have contributed to pre-service teachers' reflective practice.

Background: Using video analysis to foster reflective practices

For teachers to be successful in supporting student learning, they need skills that enable them to pay attention to student ideas. That is, they need to be able to "get into the head" of someone struggling to learn in order to make sense of his or her thinking. They need to identify subtle differences in students' understanding in order to support their learning (Rodgers, 2002). This is especially challenging as teachers can tend to focus on their own behaviors over student thinking (Star & Strickland, 2008). Successfully making sense of student thinking requires reflective practices that enable teachers to notice behaviors in order to interpret socio-cognitive activity in the classrooms (Zeichner & Liston, 1996). These reflective practices can enable teachers to question their own values and assumptions concerning student learning and build their professional knowledge through experience (Loughran, 2002). Teachers with these skills will be able to respond to and build on their students' thinking in the moment (Barnhart & van Es, 2015; Jacobs et al., 2010; Leatham, Peterson, Stockero, & Van Zoest, 2015; Stockero, Rupnow, & Pascoe, 2017) toward engaging in the challenges and opportunities of diverse classrooms.

Fostering these reflective practices can be challenging. One approach has been for teachers to journal as a way to dialogue and interact with others while tracking, reflecting on, and critiquing their experiences (e.g., Nichols, Tippins, & Wieseman, 1997). There has been a growing interest in using classroom videos to support the development of reflective practices (Rosaen, Lundeborg, Cooper, Fritzen, & Terpstra, 2008; Sherin & van Es, 2009). Video is advantageous given its affordances for conveying the subtle and complex richness of classroom learning in real time (Brophy, 2004, p. 287) while also enabling post hoc reflection and multiple viewing opportunities. Watching videos of their own teaching can help teachers make connections between their own teaching and verifiable evidence while also supporting reflection (Rich & Hannafin, 2009).

There is a body of research documenting how, through analyzing classroom videos, in-service teachers can shift attention toward student learning and cognition (Santagata, Zannoni, & Stigler, 2007; Sherin & van Es, 2005; Star & Strickland, 2008; Stockero, 2008). Much of this work has focused on teachers watching video of their own or peers' instruction. Sherin and van Es (2009) reported on a study in which in-service teachers participated in year-long video clubs. The teachers met monthly to watch and discuss video excerpts from fellow teachers' classrooms with a goal of developing their professional vision. The videos often focused on extended student activity, and results suggested that these *post facto* analyses of classroom phenomena developed the teachers' *in situ* vision of these phenomena (Sherin & van Es, 2009).

Although in-service teacher education making use of video has been gaining acceptance, little is known about what can be achieved with pre-service teachers who are just beginning to make sense of student learning. Some studies engage participants, especially pre-service teachers, in using educational research techniques to analyze video footage (Goldsmith & Seago, 2008; Schäfer & Seidel, 2015; Tunney & van Es, 2016; van Es, 2011). For instance, Blomberg, Sherin, Renkl, Glogger, and Seidel (2014) discussed two pedagogical strategies for fostering pre-service teachers' reflection patterns. McFadden, Ellis, Anwar, and Roehrig (2014) examined the use of video annotation tools among beginning science teachers who were investigating their own teaching. Much of this work has had the pre-service teachers focus on either their own performance or selected teacher–student interactions rather than an extended examination of HS students' learning content. Most closely related to the current study, Barnhart and van Es (2015) examined pre-service teachers' responses to the Performance Assessment for California Teachers as part of a course designed to scaffold teaching through video with a focus on student learning. Those pre-service teachers were attending to student ideas in a portfolio teaching assessment that involved watching preselected video clips, but less is known about using video to attend to student ideas in more open-ended and authentic teaching settings. In conclusion, what makes our use of video unique in this literature landscape is the combination of the following features: (a) prospective pre-service teachers have to develop and videotape a lesson, (b) video is focused on student learning rather than teacher moves, (c) video analysis is performed over many weeks at a level akin to qualitative education research, and (d) video analysis is used with prospective pre-service teachers who are in the process of deciding whether to pursue teaching careers.

Research contribution and focus

Building on prior work, this article contributes insights into how prospective pre-service math and science teachers can build reflective practices through qualitative video analysis. Specifically, we show how prospective pre-service teachers can learn to identify subtle differences in HS student understanding. Other research has documented challenges with scaffolding teacher noticing (e.g., Jacobs et al., 2010; van Es & Sherin, 2002). We propose a different technique: that qualitative research can be a useful tool by providing opportunities to support growth in reflective practices. This can be achieved with prospective pre-service teachers, that is, individuals who are contemplating teaching but have not yet enrolled in a pre-service teacher education program. Our focus on prospective pre-service teachers provides insights into a population that is in a nascent stage of a potential

teaching career. These individuals are new to education research and taking their first education course.

We focus on a course for prospective pre-service math and science teachers that incorporates a video analysis project. The prospective pre-service teachers teach a lesson on math and science content to HS students. They videotape the lesson and analyze the data. Then, as part of the course requirements, they write up their methods, implementation, and results. They are required to include a section in which they self-reflect on their development as a teacher related to HS student learning. In the context of our course, here we examine the following:

- How does the video analysis project enable the prospective pre-service teachers to identify subtle differences in HS student understanding in order to support their further learning?
- How does the video analysis project enable the prospective pre-service teachers to utilize their reflective practices to question their own values and assumptions concerning HS student learning?

An analysis of two prospective pre-service teachers' video projects illuminates how qualitative video analysis can foster reflective practices and suggests directions for how others could incorporate this approach into pre-service teacher education.

Research context and intervention: Pre-service science, technology, engineering, and mathematics (STEM) teacher education course

Course overview

The setting for this research was a prospective pre-service teacher education course at the University of California, Berkeley. Our course, Knowing and Learning in Mathematics and Science Education (K&L), is an undergraduate course conceived and administered by the Cal Teach campus-wide initiative.¹ Cal Teach is part of the UTeach mother program from the University of Texas at Austin. UTeach was created to prepare pre-service math and science teachers to achieve a degree in a science or mathematics discipline while earning a teaching certificate (Schweingruber, Duschl, & Shouse, 2007). K&L is a practicum in which secondary pre-service teachers are challenged to examine their beliefs about STEM learning in order to build a coherent philosophy of learning and teaching in STEM that is aligned with student-focused inquiry-based instruction. Here we spend considerable time describing the course context as a whole because course activities supported the video project to be successful.

At Berkeley, K&L is often an early experience in an education course and practically serves as a recruiting tool for the Cal Teach minor. Students in K&L are contemplating teaching and have a range of commitment: Some are firmly committed to teaching, whereas others are exploring possibilities. However, as most K&L students are not yet formally enrolled in the credentialing aspect of Cal Teach, they are considered prospective pre-service teachers. K&L typically enrolls 30–40 undergrads per semester, and there is a

¹See <http://calteach.berkeley.edu>.

range of majors across STEM fields; thus, the insights described here transcend particular majors. The size of K&L and Cal Teach has increased over time, and about 25% of K&L students go on to receive teaching credentials within the state.

The framing of K&L strongly resembles the original UTeach framework, but the specifics are unique. The course is typically taught by faculty and graduate students with backgrounds in STEM education. K&L meets for 3 hours per week. In addition, K&L students spend 24 hours conducting fieldwork over the semester in an HS classroom. Although K&L is not a traditional teaching methods course, the bulk of the emphasis is on developing a vision of HS student learning in math and science rather than a focus on instructional design, assessment, and schools. A key focus is on open-ended content problems that are initially solved in the K&L classroom. Later, K&L students choose one problem, develop a lesson, teach it in the HS classroom, videotape it, and then choose video excerpts for the focus of their qualitative analysis.

Course philosophy and analysis framework: Collaborative problem solving as a vehicle for learning to notice

K&L students are undergraduate STEM majors who typically have had a history of academic success in primarily lecture-based courses. We have found that they have a tendency to assume that their own educational trajectories and classroom experiences were reasonable because they personally have been academically successful. Yet the goal is for the K&L students to develop lessons and create classroom environments that foster classroom learning for all, while engaging in the challenges and opportunities of diverse classrooms. Key to this is awareness of the sociocognitive activity of others. This awareness is built through a progression of activities.

First K&L students are engaged in authentic science and math practices to build up their knowledge of educational possibilities. Fundamental to the K&L curriculum is a series of collaborative problem-solving activities. During problem-solving activities, the K&L students learn to notice patterns, capture those patterns symbolically, and work toward generalizability (Schoenfeld, 1994). K&L students learn how mathematicians and scientists look at problems (Schoenfeld, 1992, 1994). Some K&L content problems come directly from Schoenfeld's (1994) problem-solving courses, whereas others were developed by the instructors (see Table A1 in the Appendix for a list of the content problems). One goal of the class is to challenge some of the traditional assumptions of science and math classrooms. Not only are the problems more collaborative and open ended than traditional lecture-based college courses, but instructors play more of a facilitation role such that the class becomes a community of mathematical and scientific judgment based on appropriate standards (Schoenfeld, 1994).

After engaging in problem solving themselves, the K&L students move to reflect on their own learning processes and then consider that of their peers. Classroom conversations encourage students to share problem-solving strategies and then step back to notice the variety of approaches taken by others. These meta-conversations allow K&L students to reflect on others' thinking in math and science. Not only do K&L students reflect on their peers' approaches, they also read STEM education journal articles to gain an even broader perspective. After discussing these articles in an online forum, they are asked to reflect on K&L classroom problem solving in light of at least one article. Finally, K&L

students observe math or science classes at their HS classroom field placement. All of these course activities are associated with supporting K&L students in moving beyond personal perspectives when interpreting others' learning. The K&L students question their existing values and assumptions about learning by observing and noticing others' sociocognitive activity in classrooms.

Video analysis in K&L

We have just described some of the course activities we see as key to building up K&L students' abilities to consider learning processes different from their own. In addition, we also support students in the practical aspects of how to perform video analysis before they have to do so in their final projects. The entire K&L class watches samples of open-ended STEM activities in kindergarten–Grade 12 classroom video clips, and then, with the instructors, students discuss what they see. We hand out transcripts of the video and then engage in mini-video analysis activities. One helpful resource we have used is Hammer and van Zee's (2006) *Seeing the Science in Children's Thinking*. Building on the K&L students' input, we develop the notion of honing in on a focal episode, namely, a circumscribed string of events that we find interesting. We discuss potential analysis directions, develop the beginnings of research questions, and articulate any claims the video episode could support as evidence.

Finally, the K&L students implement and videotape their content problem lesson with HS students. Then the K&L students conduct qualitative video analysis of the HS students' learning. The project's purpose is to support the K&L students in learning to notice and interpret key features of a situation (van Es & Sherin, 2002, 2008). The K&L students use their existing content knowledge and identify important elements in a situation. For instance, K&L students may focus on episodes when HS students struggle with a particular content problem because they do not understand the assumptions or when a typically quiet student meaningfully participates. Finally, they make connections between the specific events and broader principles of teaching and learning.

In terms of logistics, we advise K&L students on key elements that increase the likelihood of meaningful video analysis. For example, we encourage them to focus their camera on one small group to capture student reasoning. Once the video data are collected, we help them develop a research direction; this may involve watching the video with K&L students during office hour meetings and suggesting ways they can leverage course readings. For instance, course readings often include Gravemeijer (1998) and Hammer and van Zee (2006), and thus we might ask what those authors would notice in the video. The collective course activities provide an opportunity to develop a coherent and effective approach to noticing and interpreting HS student learning.

K&L students write up their video analysis research in an end-of-semester final paper. At the end of the paper the K&L students are also asked to write a reflective piece "discussing what you have learned in this process that goes beyond the specifics of the problem you used." In addition, they answer the following questions:

Do you feel better prepared for some professional aspect of being a teacher? Do you feel confident in incorporating non-routine problems in your teaching? Do you feel (at

least) motivated to do so? What new questions do you now have now about being a teacher?

In our analysis, we focus on the most detailed artifact, the final paper. The final paper provides insights into K&L students' reflective practices at the end of the semester and some post hoc reflection on their developing views of learning and teaching.

Data analysis methods

When analyzing K&L students' final papers, we examined the level of detail of the video analysis presented and any shifts in views on teaching and learning. We selected two K&L student final projects involving different content problems that were paradigmatic in the sense of demonstrating shifted views on teaching and learning. These two cases were also selected because they were especially detailed in their research analysis and reflections. Using the progressive refinement of hypotheses approach (Engle, Conant, & Greeno, 2007), we began with a general question about K&L student shifts in views on learning and teaching. Then, from an initial analysis of the cases, we developed more specific hypotheses about the K&L students' views on the content problems, their video analysis, and their views on teaching and learning. That led to specific explanatory hypotheses and coding around common themes, such as students' rationalization for their choice of content problem, their observations of the HS classroom, and their own and K&L peers' experience solving their chosen content problem. Within these areas, we began noticing the key theme of moments of realization that people approach learning differently. We brought in the construct of reflective practice to help us concretize this key theme and then compared and contrasted the cases.

Analysis and results: Cases of developing views on learning and teaching while building reflective practices

We describe two cases from different final papers in which we can see K&L students building reflective practices as they draw on a variety of experiences and perspectives. The first paper was written by Anthony,² a molecular and cell biology major interested in medicine and medical education. While in K&L he was assigned to an Advanced Placement (AP) chemistry classroom. The second paper was written by Alex, a physics major considering a HS teaching career. While in K&L, Alex was assigned to an HS environmental science classroom. For both cases, we analyze the students' papers and highlight reflective practices in their qualitative video analysis (i.e., instances of going beyond personal experiences when interpreting their HS students' sociocognitive activity). Then we conclude by identifying a series of factors relevant to their building of reflective practices.

²All student names are pseudonyms.

Anthony and the candle problem: Broadening views on teaching and learning through video analysis

Motivation for the lesson choice

Anthony chose for his lesson to be based on a problem known as the candle problem. For this problem, a lit tea light is placed on a stand in the middle of a metal pie pan with a small amount of water. A mason jar is placed upside down over the candle, the candle is extinguished, and the water level rises. The purpose of the problem is to investigate why this happens.³ Anthony chose to use this problem for his lesson, saying,

I was quite surprised at the diverse thought processes of my peers in the group and class setting. Each person brought his or her unique experiences to the table and contributed something different to the discussion. In my group, we touched upon issues that never would have come to my attention otherwise, such as “changes in moles of gas within the jar,” “role of $O_2(g)$,” and “how a vacuum is produced.” Similarly, during the class discussion, groups presented even more approaches to the problem, some of which were new and some of which were familiar but presented in a different manner. Ultimately, this experience stood as a testament to the diverse learning strategies of students.

Anthony appeared to recognize the diversity of approaches and prior experiences peers brought to the problem and the positive benefits of their contributions for his own learning. He also had a growing appreciation for open-ended problems and the value of argumentation:

Working with others poses a great benefit to one’s learning experience. It brings together [K&L] students of various backgrounds to answer a single problem and this blend of ideas, experiences, and alternative points of view can greatly aid a student’s understanding. Had it not been for the group work in Education 130 [K&L], I would not have had such an appreciation for the true “open-endedness” that is the Candle Problem. In addition, the process of explaining one’s argument forces students to go beyond comprehension; they must also be able to convey and convince other students of their arguments.

When describing his decision to use the candle problem, Anthony alluded to his field placement experiences, in which students typically

resort to repetition and memorizing formulas . . . For the success of this [candle] experiment, students must go beyond the comfortable repetition of daily worksheet problems and apply those concepts to real world situations. My class normally does not partake in free-thinking problems so I believed that they would be highly engaged if given the opportunity.

Here Anthony recognized differences in problem-solving approaches between more typical classroom activities and the candle problem. Recognition of this difference was partly influential in his eventual choice of research direction. Furthermore, having observed his HS students preparing for the AP exam, he juxtaposed that rigidity with the flexibility of the candle problem and the kind of learning experience it could offer:

In preparing for the AP exam, my students became accustomed to repetitive practice problems to simulate the AP test, and I believed it would be incredibly beneficial to provide the opportunity for them to think outside the box. In this lesson, it is not the solution itself, but the process of discovering the solution that is most valuable.

³Oliver Knill, a Harvard mathematician, has a wonderful resource about this very problem at <http://www.math.harvard.edu/~knill/pedagogy/waterexperiment/> (retrieved February 25, 2016).

From his experiences with the candle problem, Anthony gained an appreciation of the value of open-ended problems for supporting his HS students' thinking processes, especially compared to the more closed-ended AP exam activities he had observed. In addition, this recognition influenced his research focus on a previously unengaged group of students becoming more engaged through surprise and self-discovery. As he himself described, his focus on student thinking processes, both in the K&L classroom and in the HS classroom, was evidence of his developing reflective practices.

Anthony's video analysis of engagement moments

For his video analysis research, Anthony had noticed that one small group of three or four students was rarely engaged in the regular curriculum, yet they had become very engaged during his own lesson. Somewhat fortuitously, Anthony had decided to videotape this group, along with another small group and a large-group discussion. For his research, Anthony was focused on surprise and self-discovery as influencing the HS students' learning. He identified moments of student excitement and then followed them throughout the lesson to find any interesting repercussions. Anthony wrote,

Eventually I focused my attention on specific [engagement moments] in which students got noticeably more engaged and excited about the material. In my data, there were a total of three [engagement moments], and each group experienced at least one of those moments. As a result, I felt the data was [*sic*] sufficient to permit me to focus on these [engagement moments] in detail, and I centered my attention on better characterizing their involvement in a student's learning experience. I specifically looked at the two student groups before, during, and after the [engagement moment], and utilized transcribed video conversations, screenshots, and group presentation papers in an attempt to answer the following two questions. 1. Does surprise and self-discovery influence learning in a scientific classroom? 2. How does surprise and self-discovery influence learning in a scientific classroom?

Consequently, Anthony defined engagement moments as moments when students were excited, surprised, and engaged in the activity, and he was able to find two interesting results. One group's participation had led group members to unexpectedly propose additional experiments and hypothesis tests about the candle problem. Prior to the engagement moment they had not seemed as interested in pursuing those hypothesis tests. The other group was traditionally unengaged during the semester and had started paying close attention to the experiment after the engagement moment. That group even brought up important data related to the engagement moment in a class discussion. In the following quotation from Anthony's work, he explains the change in students' motivation as the result of becoming empowered:

Normally, I would not have expected [this small group] to contribute to the discussion, but on this day, Student 1 raised her hand and provided the crucial piece of information that illustrated that much of the water was not formed from condensation, but rather pushed into the jar from the surrounding pie tin, "But the water level outside the jar went down!" It was amazing to see a student, who is not normally engaged in class, become engaged after being empowered by her own discovery. The surprise provided the incentive to become actively involved in the experiment, and the self-discovery encouraged her to speak up in a situation that she normally would avoid. In this case, her insightful observation proved to be the deciding factor in what could have been a heated debate.

Through video analysis Anthony both identified and gave examples of the pedagogical importance of excitement and engagement. In this way he was able to capture events that he had noticed while teaching, and in particular, some recognition of the pedagogical importance of excitement and engagement for student learning.

Concluding comments on the case of Anthony

Anthony had initially been uncomfortable with ending the lesson at a point when students did not know the “right answer”:

Though it seems only natural to want to teach students the correct answer, I realize that the role of the teacher is not to simply instruct one's students, it is to teach them. Teaching extends far beyond the realm of a solution manual, and after this experience, I do feel much more comfortable at teaching, especially with regard to incorporating open-ended problems into my own lesson plans. I do admit, I began the semester somewhat doubtful of the potential benefits of such open-ended problems. How could we just leave students without the answer! Aren't we supposed to guide them and get them back on track! However, in the end I have discovered that students are much more capable than we often realize, and it is freedom, not necessarily strict guidance, that will nurture their ability to learn.

We can see a shift in Anthony's views on teaching through the qualitative video analysis in conjunction with other course activities. Initially he believed that teachers should tell students the correct answer, and by the end he realized that not telling may ultimately be more effective. As part of this shift, he gained a growing awareness and appreciation of the value of open-ended problems in supporting his students. More broadly, Anthony recognized the diversity of approaches and prior experiences peers brought to the problem and the positive benefits of peers' contributions to his own learning. In the video project, in conjunction with other course activities, Anthony was able to capture events that he had noticed while teaching, and this project contributed to the shift in his views on teaching (and, implicitly, on student learning). By the end he came to recognize that his students were more capable than he had believed and thereby came to build reflective practices. This case shows that these collective K&L course activities could contribute to shifting a prospective pre-service teacher's views on teaching and learning.

Alex and the Fermi problem: Rethinking the role of teachers through analyzing video

Motivation for the content problem

Alex selected an order-of-magnitude problem about water usage: How much water does the city of Los Angeles use in a day? Order-of-magnitude problems, often referred to as *Fermi problems* after the famous physicist Enrico Fermi, are a type of estimation problem based on educated guesses and are common in physics and engineering (Goldreich, Mahajan, & Phinney, 1999). In the K&L classroom we had previously solved a few Fermi problems, including the one about water usage. Alex noticed that his HS students were mostly engaged in “taking notes on a lecture or video.” He “thought [that] working with a complex problem would help to not only keep the students interest[ed], but show them that there is more to science than just learning facts.”

Alex hypothesized that with a Fermi problem his students could thus “work through a complicated situation that doesn't have some exact answer that they need to reach.” Having previously solved this problem himself in the K&L classroom, Alex reflected on

that previous experience, in which there had been sufficient time to try multiple solution paths, which allowed him to make note of multiple approaches. Furthermore, Alex remembered having difficulty drawing boundaries around the problem: He had been unsure whether to focus on personal water usage or industrial water usage.

Alex extrapolated from his K&L experiences to make sense of how his HS students might respond to this problem. Specifically, Alex recalled that it had been difficult for him to resist looking up the correct answer online. He also recalled being frustrated because he had wanted the instructors to tell him the answer. He expected similar challenges in the HS setting: “I anticipate some unhappiness with not receiving the answer, and my plan is to ask them how someone would measure that [magnitude] in the first place.” Furthermore, Alex remembered learning from peers’ problem solving. Another group had attempted to visualize a bathtub filled with milk gallons to estimate the amount of water one uses in the shower. The other group’s productive approach led Alex to recognize the value of approximating and visualizing. Thus, he drew on the K&L classroom activities and observations of his HS classroom in choosing the Fermi problem and developing his views of teaching and learning.

Alex’s video analysis of problem-solving strategies

For his video analysis Alex focused on problem solving and a book chapter on solving order-of-magnitude problems (Goldreich et al., 1999). As was required in K&L, Alex had a conversation with one of the instructors, and through that conversation his interest in problem-solving strategies became apparent. The instructor provided him with a highly accessible book chapter on solving order-of-magnitude problems and suggested that he analyze his data by comparing his students’ strategies with those listed. Similar to Anthony’s case, Alex’s video data consisted of HS students working in small groups solving the assigned content problems, but his video analysis strategies provided different insights.

Based on the problem-solving approaches described in the book chapter, Alex categorized the HS students’ problem-solving approaches and used that as a basis for analyzing his students’ thinking. Alex found that some strategies were easier to detect in the data than others, and he hypothesized why. For example, the strategy of dividing the problem into smaller pieces was easy for him to observe compared to intuitive estimation, both of which were strategies named in the book. Alex hypothesized that this difference was due to the type of behaviors involved in enacting the strategies, with some behaviors being more overt than others. He recognized that intuitive estimation may go unnoticed “because the students might use it many times but not verbalize it.” He reflected on the limitations of this video analysis approach, noting that “it is possible they used this strategy more than I counted.” Alex recognized a noticeable limitation of video analysis and became more aware of what dimensions of student thinking are accessible to the teacher, an example of some growing reflective practices.

Alex concluded his final paper by discussing the relative frequency of the various problem-solving strategies he had observed. He found that a strategy involving dividing the problem into small manageable chunks and a strategy of educated guessing were most common. As an example of the dividing-the-problem strategy, Alex provided transcript evidence that his students isolated various factors in water usage to address one at a time. In particular, he provided the following student quote: “First let’s do one person—how many gallons does it take [one person] to take a shower?” As an example

of the guessing strategy, Alex posed: “Think about how big your washing machine is.” From observing the students’ strategies and differences in their frequency Alex concluded, “It seems that even without training in these specific techniques, there are some problem-solving strategies that this group of students naturally use to approach a complex and unfamiliar problem.” On the basis of this frequency analysis, Alex hypothesized that students would require greater support in enacting low- compared to high-frequency strategies. He was able to use the strategies outlined in the book chapter to conceptualize his HS students’ problem-solving skills and recognized the need for varying scaffolds to enable student success.

Concluding comments on the case of Alex

Through these experiences, by the end of the semester Alex developed a sophisticated view of learning and teaching science in the classroom by rethinking his role as a teacher. Although we cannot be certain what Alex retained from the experience, we note the following two points. In the reflection section of his final paper Alex discussed open-ended content problems as a lens into his views on the practice of science and learning in classrooms:

I definitely feel comfortable using problems like this [when I’m teaching a] class because they can easily fit into a physics class and all science should allow the students to just explore an idea for a while. I think it is terrible that so many science classes end up presenting things as fact and expecting the students to just learn it and accept it. Science is supposed to be all about testing ideas and trying to figure out how the world works, not looking up answers in a book.

Furthermore, reflecting on his teaching skills and comfort level Alex wrote the following:

I felt much more comfortable leading this class tha[n] I have in other lessons I’ve given and in addition to just having more experience, I think this type of problem takes some of the pressure off the teacher because the students are focused on each other. It makes the class less of a formal class and more of an informal discussion. Also, with spending so much time on the problem analysis, I felt I had a really good idea of what I wanted to do and what I wanted from my students, so I wasn’t nervous at all when I stood in front of them.

To arrive at this point where he felt comfortable with open-ended problems Alex rethought his role as a teacher and developed a sophisticated view of learning and teaching science in the classroom. Stemming from his early-semester observations of the HS classroom, Alex purposely chose a complex problem that he thought would help build a view of science as more than learning facts. Furthermore, he had extrapolated from his own and K&L peers’ challenges and success when solving this same problem to predict how his HS students might respond, an example of focusing on student thinking.

After implementing the lesson and watching the video, Alex was able to use existing problem-solving strategies to conceptualize his HS students’ problem-solving skills, and he recognized some limitations of video analysis methods in capturing student thinking. Thus, through these experiences with other perspectives Alex became comfortable with these problems while developing his views of learning and teaching.

Highlights from both cases

It is gratifying to witness undergraduate students with no prior educational research background arriving at grounded inferences and implications based on qualitative video data analysis. Both K&L students drew on their K&L experiences when choosing their specific math or science content problem and conducting the video analysis project, which resulted in their developing views of learning and teaching and their building of reflective practices. Both K&L students became more comfortable with open-ended content problems and knowledgeable about perspectives other than their own. Yet their research projects resulted in different realizations. Anthony was able to see the pedagogical importance of excitement and engagement in student learning, whereas Alex's project enabled him to see that some problem-solving approaches are more common than others and that certain problem-solving approaches may require extra support.

In addition, the K&L students were struggling with different dimensions of teaching, and yet both were developing sophisticated views. Anthony rethought his views on the role of teachers and ultimately came to see the value in not always telling students the correct answer. Alex was able to move past initial uncomfortableness with open-ended problems.

Although there were a range of K&L student experiences, Alex and Anthony were certainly not alone in this achievement. It was a requirement of the course activities that all K&L students describe and anticipate a variety of problem-solving approaches to their HS lesson that were different from their own. Thus, to some extent, all students engaged in reflective practice. On their final papers, many students demonstrated impressive qualitative analyses and expanded their views of what good teaching and learning looks like. We chose to highlight these stories as paradigmatic cases. Analysis of our K&L students' final papers suggests that the video projects in conjunction with the K&L classroom activities provided opportunities for the development of reflective practices along with shifts in students' views of learning and teaching.

Looking across these cases, we hypothesize that several factors seemed to contribute to K&L students' successful video projects and the development of their reflective practices:

- Appreciating open-ended content problems for promoting thinking and learning
- Recognizing the diversity of problem-solving approaches from the K&L classroom activities and building that recognition into subsequent lesson plans
- Identifying and noticing key teaching and learning moments in the classroom
- Extrapolating from one's own and peers' learning to HS students' learning
- Rethinking one's role implementing the content problem in the HS classroom and teaching more broadly
- Valuing the attention to detail required in qualitative video analysis

These factors are potential design principles for others who are interested in building reflective practices through qualitative video projects. The first two principles focus on open-ended content problems and having the problems be implemented in such a way that one sees their value in enabling many individuals to use a variety of problem-solving approaches to promote thinking and learning about the content. The next two principles focus on the implementation of content problems in HS classrooms as an opportunity to notice key teaching and learning moments and then make connections back to one's own

and peers' learning. Making those connections is key for the next principle, which involves using all of these experiences to then rethink one's role in teaching. Finally, throughout it all and when conducting qualitative analysis, attention to the details of learning and teaching is central. These design principles could be applicable to the design and implementation of pre-service teacher education classes along with possibly in-service teacher education opportunities with similar aims. In addition, although our focus was on secondary education, a modified version of these principles could possibly guide the implementation of a course focused on math and science education and aimed at elementary pre-service teachers.

Discussion

This article provides the reader with an opportunity to see how prospective pre-service math and science teachers can build reflective practices through a course centering on qualitative video analysis. We have shown that an in-depth video analysis project focused on HS student learning, along with other course activities, can provide opportunities for K&L students to build reflective practices. Through this approach prospective pre-service teachers can learn to identify subtle differences in HS student understanding and reflect on their growth as a teacher. Furthermore, we also posit key K&L classroom structures through six design principles to which we attribute much of our success in building reflective practice.

It is important to consider these results in light of our population and the setting. Our K&L students did not have backgrounds in educational research, yet their analyses were frequently subtle and meaningful. K&L students whom we highlighted in this article were able to identify detailed differences in HS student understanding and utilize those differences to support further learning. An example of this is when Alex came to categorize his HS students' problem-solving skills. Some K&L students were also able to utilize their reflective practices to question their own values and assumptions concerning student learning, such as when Anthony came to recognize the value of diverse problem-solving approaches and the value of not telling the right answer. These results are noteworthy in light of existing research that has documented various challenges with teacher noticing, especially around student thinking (Barnhart & van Es, 2015; Jacobs et al., 2010; Sherin, Russ, & Colestock, 2011; Star & Strickland, 2008; van Es & Sherin, 2002). Existing research has examined scaffolds for supporting teacher noticing when analyzing student ideas (e.g., Brunvand & Fishman, 2006) and in the context of watching preselected video clips (e.g., Barnhart & van Es, 2015). Building on that prior research, we shed light on prospective pre-service teachers' analysis of student ideas in the context of a lesson they designed and taught, thereby potentially impacting their agency and ownership in a real-world setting where they were using video analysis to develop their views of teaching and learning. Furthermore, uniquely the video analysis was performed over many weeks at a level akin to qualitative education research, and this was done with prospective pre-service teachers who were in the process of deciding whether to pursue teaching careers. Here we argued that this authentic and in-depth approach can be productive for facilitating sophisticated views of teaching and learning.

Importantly, this was the first education course for many K&L students, who were not yet enrolled in a formal pre-service teacher education program, yet the outcomes of

engaging in course activities went beyond close analysis of student learning. As shown in the selected excerpts, K&L students were able to use their experiences to support their evolving views of teaching and learning, to rethink their roles as teachers, and to broaden their perspective of what HS students are capable of. As our population was in a nascent stage of their teaching career, these results are encouraging and suggest that there may be further value in examining prospective pre-service teachers specifically. To an extent K&L serves as a recruiting course for the Cal Teach program, and future work may examine this approach in light of other recruiting techniques.

Implications for pre-service STEM teacher education

Having a university student running an unconventional math or science lesson along with videotaping that lesson may have influenced the high schoolers' engagement and attention. This in turn may have influenced the video collected and the subsequent analysis. Thus, K&L students were more likely to have "cool data" and be able to reflect on the learning of math or science content in more meaningful ways because of it. Clearly not all settings will have the extensive resources that K&L did. However, future work should similarly emphasize a flexible setting in which one can be successful in implementing an unconventional math or science problem. Furthermore, it is important to note that many of the K&L instructors themselves had experience and skills in conducting qualitative research involving video analysis. These skills enabled them to scaffold the practice rounds of video analysis and support the K&L students after they collected video. It may be useful for other instructors who aim to implement a similar course to have those experiences and skills. Yet, we do note that K&L was often cotaught, and although one instructor might have had those skills, often the other was learning while doing. Finally, future work may more explicitly examine which of the relevant structures and design principles most strongly contribute to fostering reflective practices in traditional undergraduate methods courses and professional development workshops.

Implications for the use of video

When working with as flexible a tool as video (e.g., Gaudin & Chaliès, 2015; Rich & Hannafin, 2009; Zhang, Lundeberg, Koehler, & Eberhardt, 2011) it is important to articulate one's goals. Here we have added a new use of video in the pre-service teacher classroom, namely, to perform in-depth qualitative educational analysis, which can provide new opportunities for building reflective practices. These results are important in light of an understanding that teacher noticing is a critical part of professional development that can lead to changes in classroom practice. Yet, little is known about how to scaffold teacher noticing (Schoenfeld, 2011) and what interventions can be successful. The proposed design principles have the potential to be helpful in the pragmatic design and implementation of interventions that use qualitative video analysis to support teacher building of reflective practices.

Conclusion

Our course provided prospective pre-service STEM teachers with an opportunity to build a rather sophisticated vision of themselves as teachers and their HS students as learners that we hope they will carry forward with them. With so many uses of video in teacher education, here we have demonstrated one new approach, based on qualitative video analysis, that we contend was instrumental in our course outcomes. Going forward, our goal is for qualitative video analysis to be more widely used as one tool to support math and science teachers in building sophisticated visions of themselves as teachers and their HS students as learners.

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Appendix

Examples of Math and Science Content Problems That Have Been Used Successfully in Both the K&L Classroom and K&L Students' Qualitative Research Projects

Table A1. Examples of Math and Science Content Problems That Have Been Used Successfully in Both the K&L Classroom and K&L Students' Qualitative Research Projects

Problem	Problem description and notes
6-inch problem	Provide students with 8.5×11 " sheets of paper. "Find 6 inches out of an 8.5×11 " sheet of paper without using a ruler. Find more than one way to do it. Write down instructions (with words and/or pictures) for someone else to follow each of the different ways you found."
Multiplication table	Provide students with a 10×10 multiplication table. "Find something interesting in the multiplication table. Find as many patterns as you can in this table." Follow-up instructions: "Think about the relationship between rows, columns, and diagonals. Which patterns seem more or less complex, and why? Try to describe and explain your patterns mathematically."
Parking meter problem	A parking meter has the following rates posted: 2 minutes for each nickel, 5 minutes for each dime, and 12 minutes for each quarter. What sense can you make of these rates? How might one extend this list? What are different combinations of coins that make up a quarter, and what are the consequences of different orders of inserting these coins? This meter has a 1-hour maximum. If you have lots of silver in your wallet, what might be your best strategy of inserting coins, given the alternative conditions that the meter has expired, the meter is at 10 minutes, and the meter is at 15 minutes? What "school content" might emerge from engaging this problematized situation? What media, inscriptions, and reasoning did you employ for the above? Why? Invent a better problem for this given situation.
Fermi	Estimation problems. The purpose of these problems is to be really clear about the assumptions you make. These problems are named after a physicist, Enrico Fermi. He was known for making very good approximations with few details. Here are some examples of Fermi problems: How much water does the city of Los Angeles use in a day? How much money is in an armored car? How many trees are in Yosemite National Park? How many trees would you save if all of the Berkeley undergraduate textbooks were available online? How many cells are in an adult-size human body? Estimate the total number of hairs on your head. How much milk is produced in the United States each year?
Sisters problem	Do men have more sisters than women do? [The intuitive but incorrect answer is yes.]
RC Cola problem	The situation: RC Cola is having a promotional under-the-cap contest. An extraordinarily long line has formed in front of an RC Cola vending machine, and behind the machine an armada of RC Cola supply trucks keep stocking up this one machine until the promotion ends. The good people at RC Cola have designed the promotion with a 1 in 6 chance of winning. That is, one out of every six bottle caps produced for the promotion is a winning cap, but all the bottles are mixed up randomly. I am observing the RC Cola enthusiasts. At their turn, each person pumps cash into the machine and keeps buying bottles and checking caps until they've won. Upon receiving a winning bottle cap, each consumer shouts out the number of bottles they had to buy to get their win, then leaves, so that the next person walks up to the machine, and so on. The question posed to me, the observer, is this: "Hearing all of these numbers being shouted out for hours, days, weeks on end, which number will I hear shouted more than any other?"
Owl and snake problem	A mystery relationship: A biologist specializing in screech owls found a nest that contained both owl eggs and—of all things—snakes! While some snakes are known to eat bird eggs, these snakes were too small. They also had an unusual characteristic: They were naturally blind. As she watched the nest for a few days, the biologist noticed that the mother owl allowed the snakes to live in the nest unharmed. This seemed strange, since owls generally eat snakes or feed them to their young. The biologist had a hard time explaining this unexpected owl behavior. Can you explain the relationship between the owl and the snakes? What are your facts and evidence? Create an argument about what you think is going on, based on the evidence you listed above. What other information would help you solve this puzzle? ^a
Candle problem	Experiment: (1) Fill pie tin with water (less than half way). Put tea candle in water—make sure water level does not go over candle. (2) Light candle and put small mason jar over it. (3) Be sure to leave jar in place [Note: Students will see the water level rise.] (4) Observe (carefully) what happens and write it down. Questions: Why does the water level rise when the jar is placed over the candle on a tray of water? Why does the flame go out? Why does the water level rise?
Cube problem	Suppose you had a glass cube half filled with blue liquid. If it were sitting on the desk and you looked at it from above, you'd see a—What would you see? What would be the shape of the surface of the water?—square, right. Now, what if we tilted this cube so that it were standing on its tip and you had your finger way up on the diagonally opposite tip such that it was standing at its tallest possible, with your finger directly above the bottom tip. So if you again looked at this cube from the top, what would be the shape of the surface of the water? Come up with two or three three-dimensional models to illustrate this, then come up with a two-dimensional representation of the model on paper. Which models/materials/representations are better/worse for this? Why?

Note. K&L = Knowing and Learning in Mathematics and Science Education; RC Cola = Royal Crown Cola.

^aThis problem was originally developed by Sarah Henson at the University of Maryland.